CORNING GLASS WORKS

ELECTRO-OPTICS LABORATORY

RALEIGH, NORTH CAROLINA

# IMPROVED SCREEN FOR REAR-PROJECTION VIEWERS

Technical Report No. 20

Date - March 31, 1967

Period Covered - March 3, 1967
to
March 31, 1967

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ABSTRACT

This report discusses the ambient light sensitivity of rear projection screens, which is caused by their non-zero diffuse reflectance. Theoretical and experimental considerations indicate that the addition of absorbing material in a screen for the purpose of decreasing the diffuse reflectance is accompanied by a corresponding loss of light and screen brightness.

Prototype 12" x 12" Fotoform® screens were received but were unacceptable because of buckling during heat treatment.

Beaded screens have been fabricated by several processes, and work is continuing to improve the quality of the screens.

Twenty pounds of glass ceramic powder was received, and suitable techniques of fabricating screens from this powder are being investigated.

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## I. Sensitivity of Screens to Ambient Light

A. The contrast of an image projected onto a rear projection screen varies with the level of ambient illumination because the screen has non-zero reflectivity. If $\gamma_o$ is the contrast without ambient illumination, and $\gamma$ is the contrast with an ambient illumination $I_a$, then [1]

$$\frac{\gamma}{\gamma_o} = \frac{1}{1 + \frac{I_a}{I_p} R_d} \quad , \qquad (1)$$

where $I_p$ = projection illumination, and $R_d$ = diffuse reflectance of the screen when diffusely illuminated. Here it is assumed that the ambient and projected light have the same spectral distribution, that the viewer or detector is at the $\theta = 0$ position, i.e. on-axis, and that the ambient light is incident only on the viewing side of the screen. The diffuse reflectance $R_d$ is the physical property of a screen which causes the degradation of contrast under ambient illumination.

Equation (1) is plotted in Fig. 1 as $\gamma/\gamma_o$ vs. $I_a/I_p$ with $R_d$ as a parameter. Since $0 \leq R_d \leq 1$, the top and bottom curves represent theoretical limits. One manufacturer of rear projection screens states that as a working rule, room illumination should be not greater than the illumination through the screen from the projector, i.e. $I_a/I_p \leq 1$. For example, if it is required that the degradation of contrast be $\leq$ 10%, $R_d$ must be $\leq$ 11%. The value of $R_d$ becomes less important for $I_a/I_p < 1$, but for $I_a/I_p > 1$, $R_d$ must be small or else large reductions in contrast will result.

1. See memo from Nov. 23, 1966.

B. Measurement of $R_d$

1. The apparatus used to measure $R_d$ for samples of screen materials is shown in Fig. 2. Light from a circular fluorescent lamp passes through a sand-blasted glass diffuser and illuminates a sample. This method of illumination simulates typical ambient illumination. Light which is reflected from the sample is imaged onto a pinhole in front of a PM tube, and the DC output voltage of the tube is recorded. A magnesium oxide sample with an $R_d > 95\%$ was used as a standard in determining $R_d$ for the screen samples. Measurement of a cover glass which was painted flat black on one side showed that the amount of specular reflection reaching the detector was negligible.

2. Theoretical Curve and Experimental Results

Theoretical values of $R_d$ as a function of axial gain have been calculated. When light strikes a non-absorbing rear projection screen, part of it is forward scattered, part back scattered, and part is trapped by total internal reflection. Since the screen is non-absorbing, it is reasonable to assume that half the trapped light eventually is scattered forward and half backward. Then $R_d$ is given by the fraction of the incident light which is back-scattered plus half of the fraction which is trapped.

Based on this reasoning, a theoretical curve of $R_d$ as a function of axial gain for non-absorbing screens was calculated and is shown in Fig. 3, along with measured data for some Corning and commercial screen materials. The Corning materials in general lie near the theoretical curve, as expected, while the commercial materials have low $R_d$'s and lie below the curve. One reason the commercial materials do not obey the theoretical curve is that absorbing material was added to them in order to decrease $R_d$. This can be seen by considering Fig. 4, in which is plotted a theoretical curve of $T_{45}$ vs. axial gain for non-absorbing screens. The Corning materials are grouped closely about the curve, while the commercial materials fall far off the curve. Table 1 shows that the measured $T_{45}$ values for the commercial materials are 40% to 60% below theoretical predictions, while the $T_{45}$ values of the Corning materials are within 10% of theoretical predictions. So reduction of $R_d$ by the addition of absorbing material is accompanied by large loss of light and a corresponding reduction in screen brightness.

## II. Screen Fabrication

### A. Thin Layer Fotoform® Glass Screens

Two 12" x 12" and two 8" x 10" thin layer Fotoform® screens have been received. (See Fig. 5 for an illustration of this type of screen). Improper surface preparation caused the screens to bow and curl up slightly during heat treatment. These bowed screens could not be ground and polished, hence one of the scattering layers could not be removed, and this extra scattering layer decreases the brightness and resolution of the screens. Other screens are being prepared.

B. Lenticular Screens

1. Bead Deposition

By using a settling process similar to that used in making phosphor screens we have fabricated small (2" x 2") lenticular screens of -150 mesh clear glass beads on glass substrates. The bead layer obtained in this way is thin and fairly uniform. The beads are loosely bound to the substrate and can be wiped off easily, however the beads can be fused to the substrate, giving a sturdy screen. This settling process appears impractical for fabricating large screens because the process is very slow (8 hours), and large volumes of settling solution are required for each screen.

Several 8" x 10" bead screens have been fabricated using a casting plastic. The plastic is in a liquid state, and the addition of a catalyst causes it to solidify. To make these screens, a thin sheet of plastic was poured, and after the surface of the plastic became tacky, beads were spread over it. This technique inherently tends to give a single layer of beads, since a single layer will shield the tacky surface from any remaining beads. The plastic was allowed to solidify, and then the beads which did not adhere were wiped off. These screens produce bright, pleasing images on-axis, however the surface of the plastic, and thus of the finished screen, is irregular, giving undesirable and unpredictable off-axis viewing characteristics.

Another resin, methyl methacrylate, was investigated. This resin is also a liquid and solidifies when a polymerizing agent is added and the mixture is heated. We found this resin is very slow to polymerize, and attempts to speed up the process by heating the resin produced bubbles. We have not fabricated any screens using this resin.

If a thin, uniform layer of a bonding material can be deposited on a glass substrate, bead screens can be fabricated which do not have the irregular surface of the screens mentioned in the previous section. A screen of this type is illustrated in Fig. 7A. Casting plastic thinned with acetone was sprayed on glass plates in an attempt to obtain such a thin, uniform bonding layer. This attempt proved unsuccessful because the acetone evaporated out of the plastic before the spray reached the substrate, and since the unthinned plastic is very viscous, it beaded up and formed an irregular surface on the glass, rather than forming a thin layer. Less volatile solvents will be tried.

2. Masked Beaded Screens

In the previous report it was shown that if an absorbing layer is added to the viewing side of a bead screen such that it covers all but the "tops" of the beads, then the screen's sensitivity to ambient light is greatly reduced while the image brightness is not degraded. This kind of screen is shown in Fig. 7B.

Several screens of this type were fabricated by spraying beaded screens with flat black paint. Fig. 8A shows an image projected on a mosaic of four beaded screens, two of which have been sprayed. The image is not as bright on the sprayed screens because the paint covers the tops of the beads, and since the refractive index of the beads and the resin are almost the same, only slight refraction occurs, hence most of the light does not pass through the window at the top of the bead. The paint can be removed from the bead tops by carefully wiping the screen with a solvent. This was not done because the beads forming the screens shown in Fig. 8 were not fused to the substrate. Fig. 8B shows the mosaic viewed in reflected light, i.e. shielded from any back illumination. Note that the sprayed screens appear black while the others appear white.

These beaded screens also tend to sparkle when viewed off-axis, because some of the projection light is specularly reflected from the beads and passes through voids in the screen to reach the viewer. The masking technique removes this sparkle by absorbing the reflected light.

High index beads ($n=1.9-2.2$) are being made and will be used in subsequent screens. With these beads, screens can be made which have a high efficiency, high gain and small brightness variation over $\pm 45^{\circ}$.

C. Glass Ceramic Screens

This type screen is illustrated in Fig. 6. Twenty pounds of a ground and sized glass ceramic (AS-9) were received, and several screens have been fabricated. Since a single layer of particles is not a requirement for screens made from glass ceramic powders, the powder was simply mixed with liquid bonding agents and sprayed onto a substrate. This gave unsatisfactory results because of the beading problem mentioned earlier.

Work is continuing to develop suitable techniques for fabricating prototype rear projection screens made from any of the above mentioned materials.

TABLE I

Comparison of the Theoretical and Measured Values of $T_{45}$ and $R_d$ of Some Commercial Materials and Corning Materials

| Commercial Materials | G(o) | $R_d$ Theo. | $R_d$ Meas. | $T_{45}$ Theo. | $T_{45}$ Meas. | K* |
|---|---|---|---|---|---|---|
| SN2149 | 1.2 | 60% | 46 % | 21 % | 17 % | 0.81 |
| LS60G | 3.8 | 31 | 6 | 45 | 25 | 0.56 |
| RAVEN | 5.0 | 25 | 10 | 53 | 33 | 0.62 |
| LS60STG | 5.8 | 22 | 6 | 58 | 27 | 0.47 |
| LUX 70 | 6.2 | 20 | 16 | 60 | 37 | 0.62 |
| Type 4 | 6.7 | 19 | 6 | 62 | 24 | 0.39 |
| **Corning Materials** | | | | | | |
| AC-18A | 1.6 | 52 | 53 | 26 | 23 | 0.89 |
| AC-18C | 1.7 | 50 | 32 | 27 | 25 | 0.93 |
| AD-19 | 2.4 | 41 | 31 | 34 | 33 | 0.97 |
| AD-21 | 4.1 | 30 | 17 | 47 | 44 | 0.94 |
| AD-62 | 2.8 | 38 | 34 | 37 | 36 | 0.97 |
| AD-64 | 4.8 | 26 | 28 | 52 | 53 | 1.02 |
| AV-12 | 2.1 | 45 | 48 | 31 | 29 | 0.94 |

$$*K = \frac{T_{45}\ \text{(Meas.)}}{T_{45}\ \text{(Theo.)}}$$

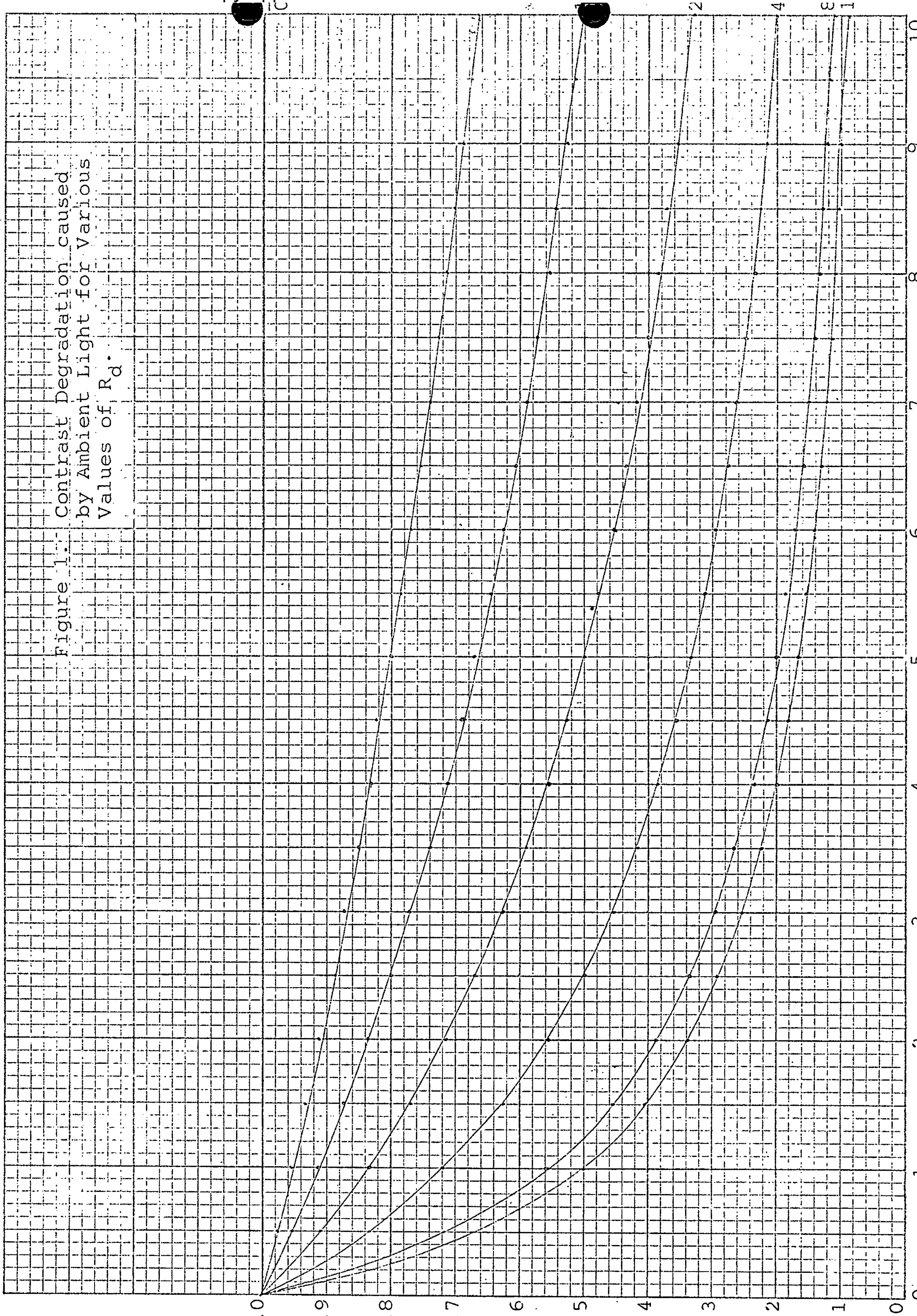
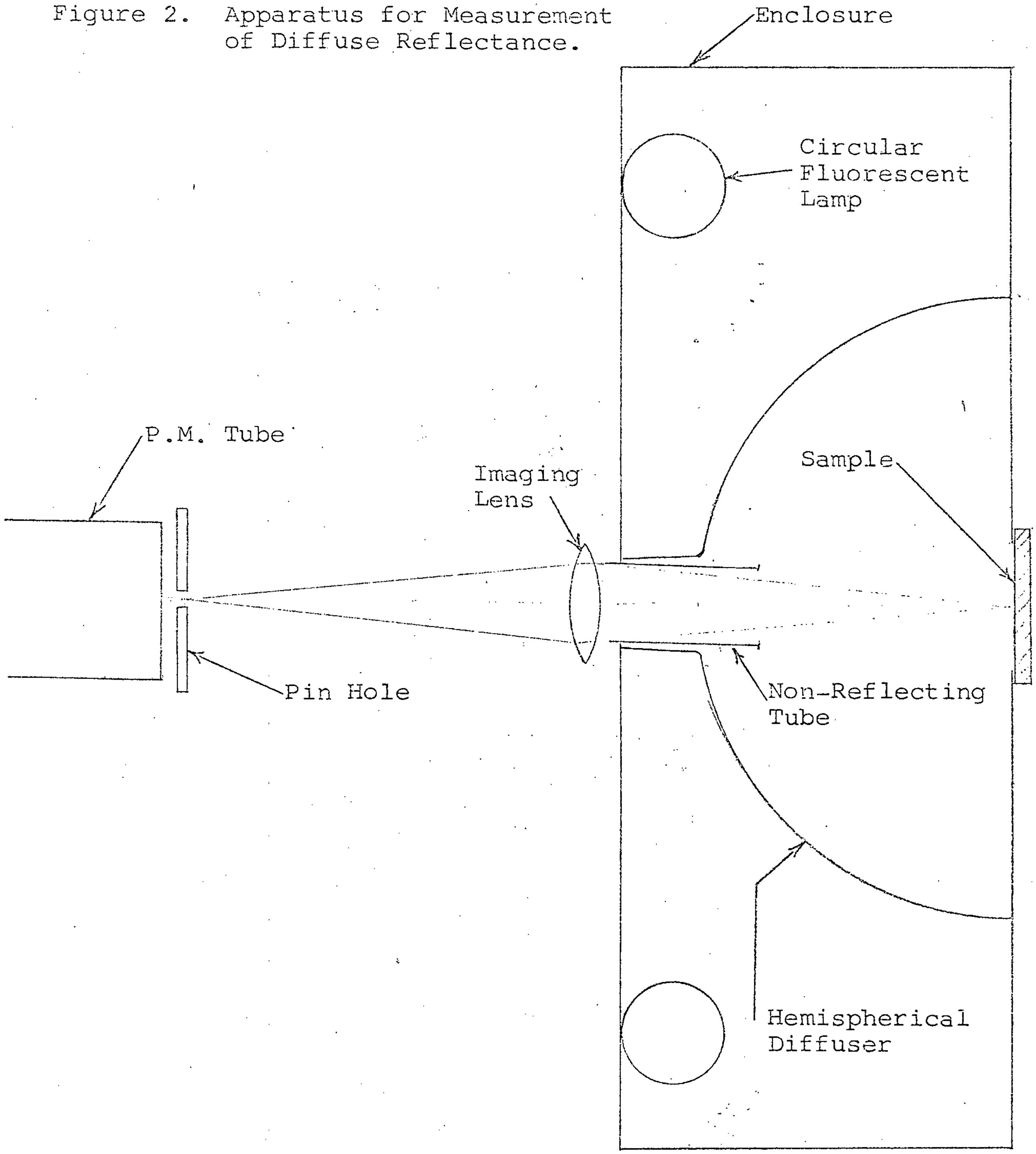



Figure 1. Contrast Degradation caused by Ambient Light for Various Values of $R_d$.

Figure 2. Apparatus for Measurement of Diffuse Reflectance.



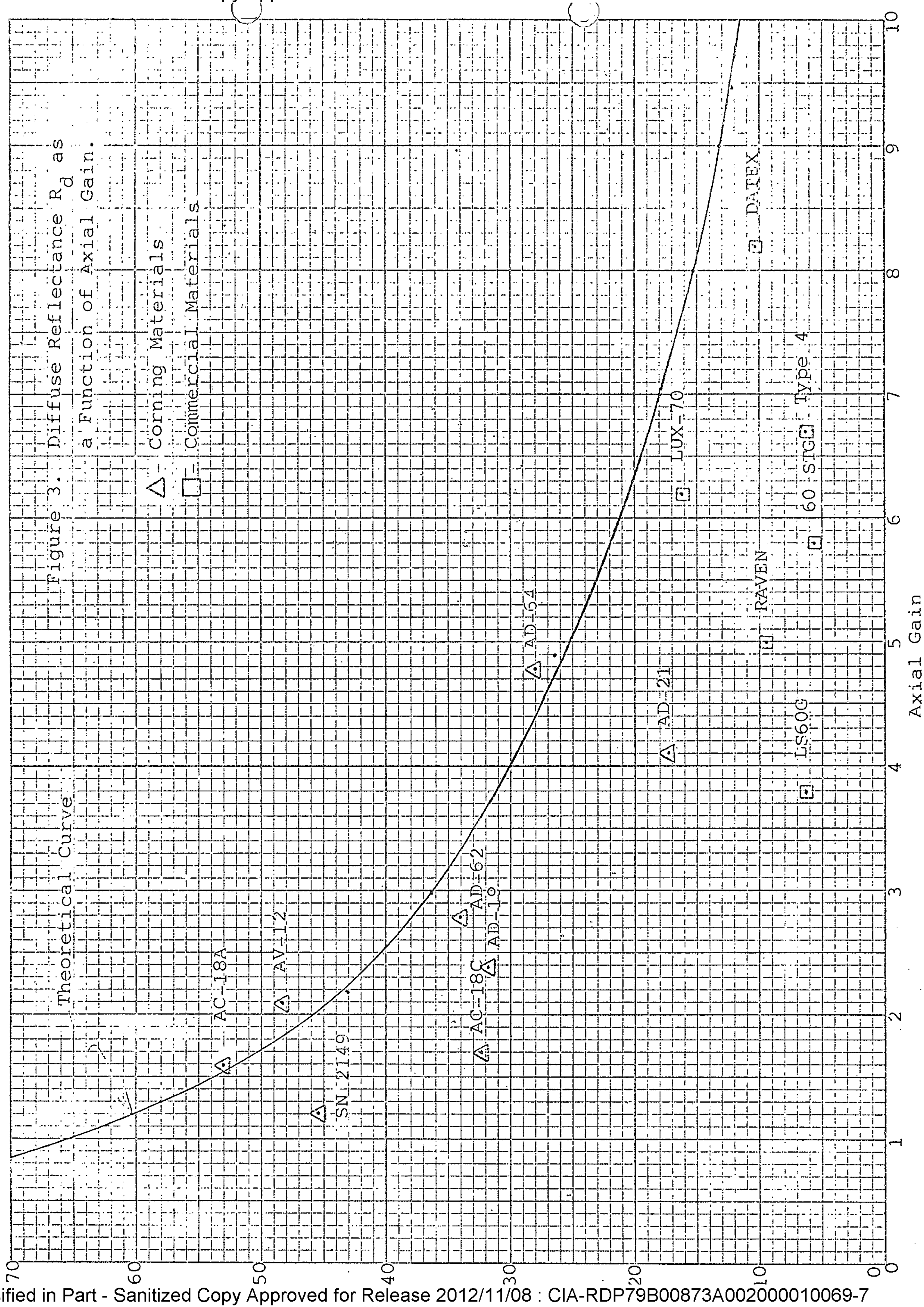



Figure 3. Diffuse Reflectance $R_d$ as a Function of Axial Gain.

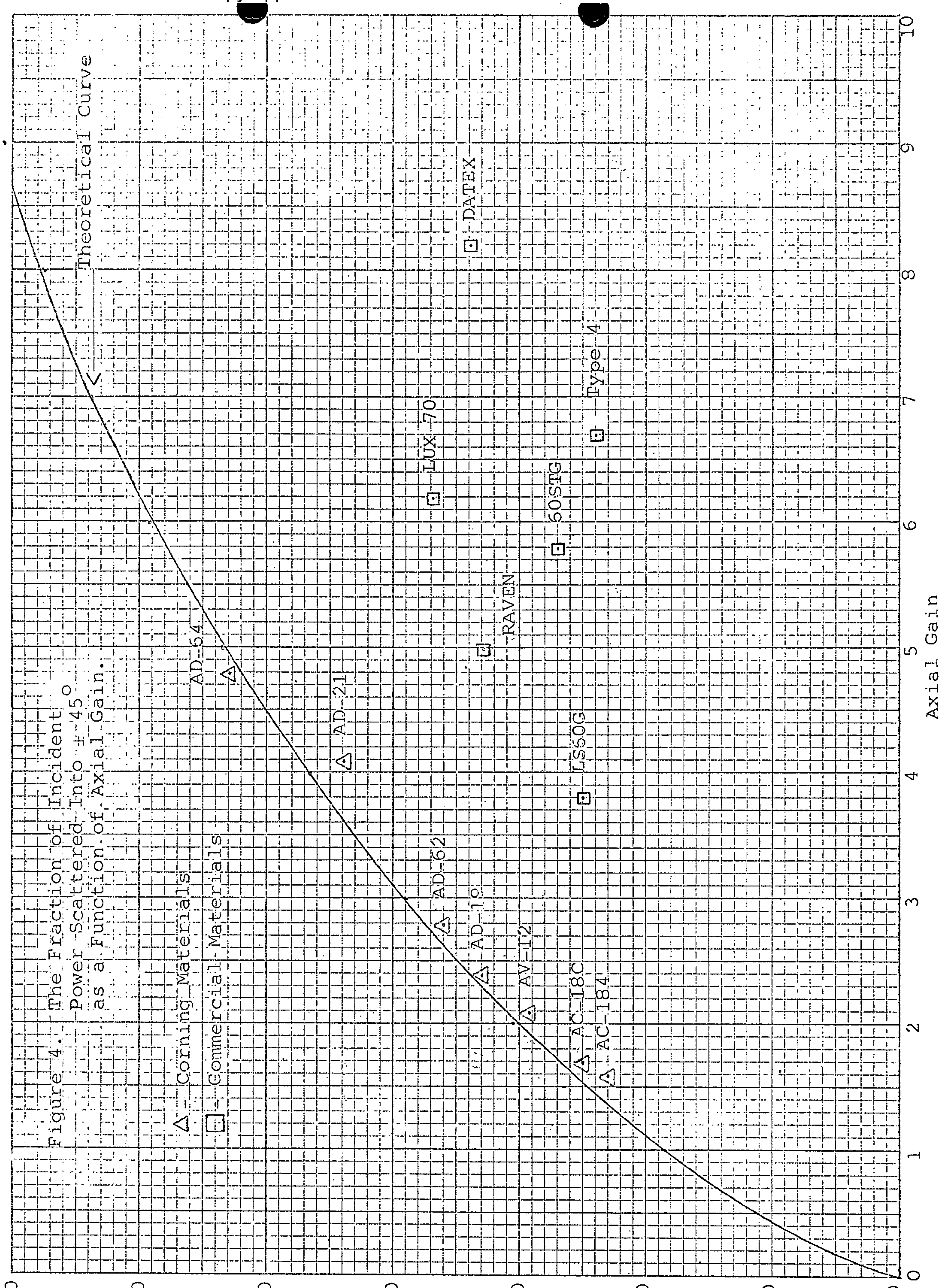



Figure 4. The Fraction of Incident Power Scattered Into ± 45° as a Function of Axial Gain.

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Fig. 5. Fotoform® Glass Screen

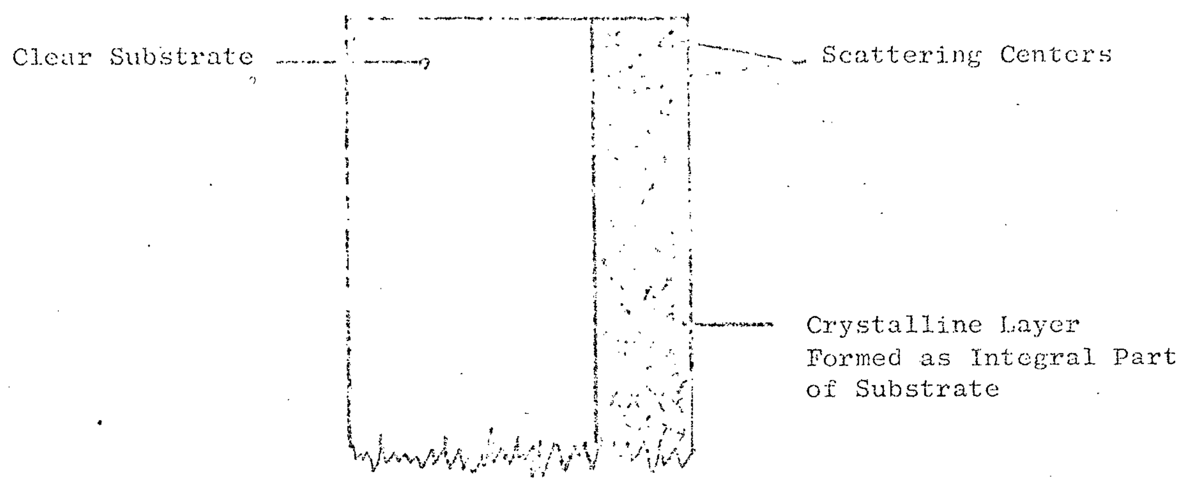



Fig. 6. Glass-Ceramic Screen

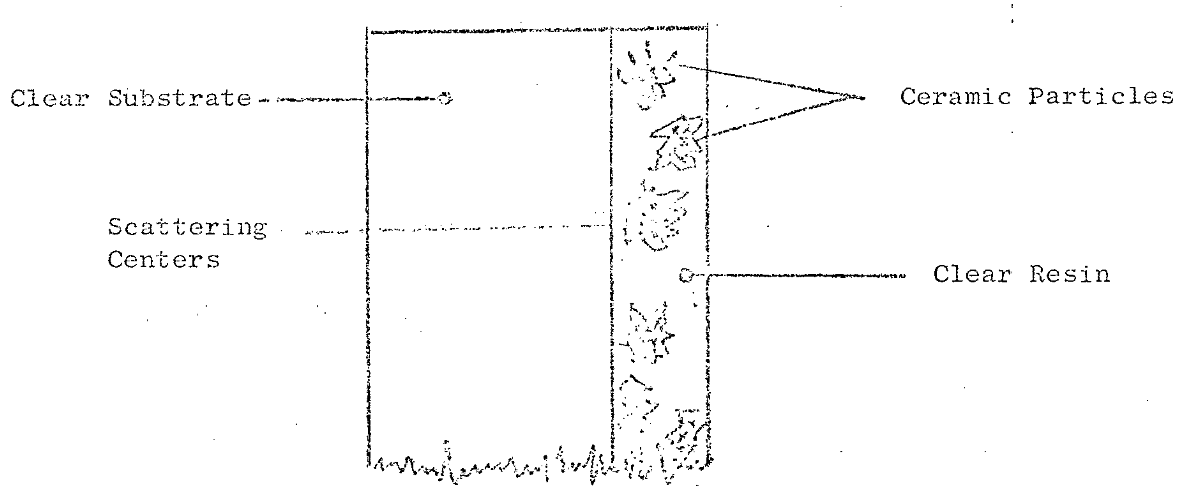
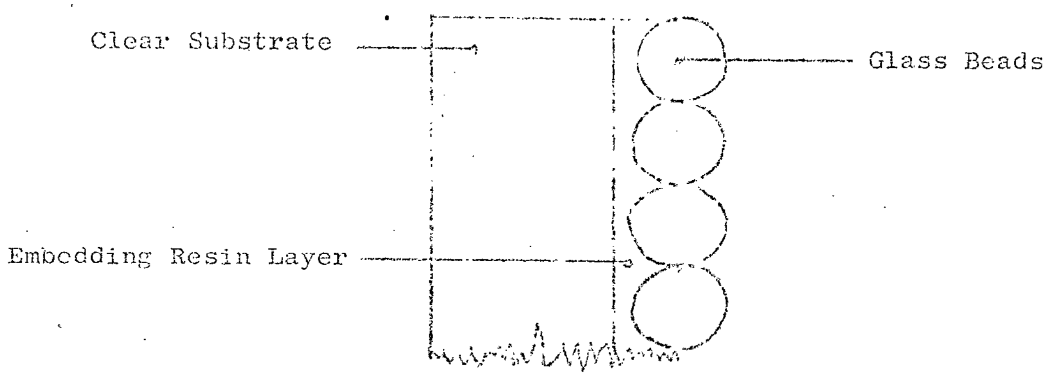


Fig. 7. Lenticular Screens

A. Regular Beaded Screens




B. Masked Bead Screens

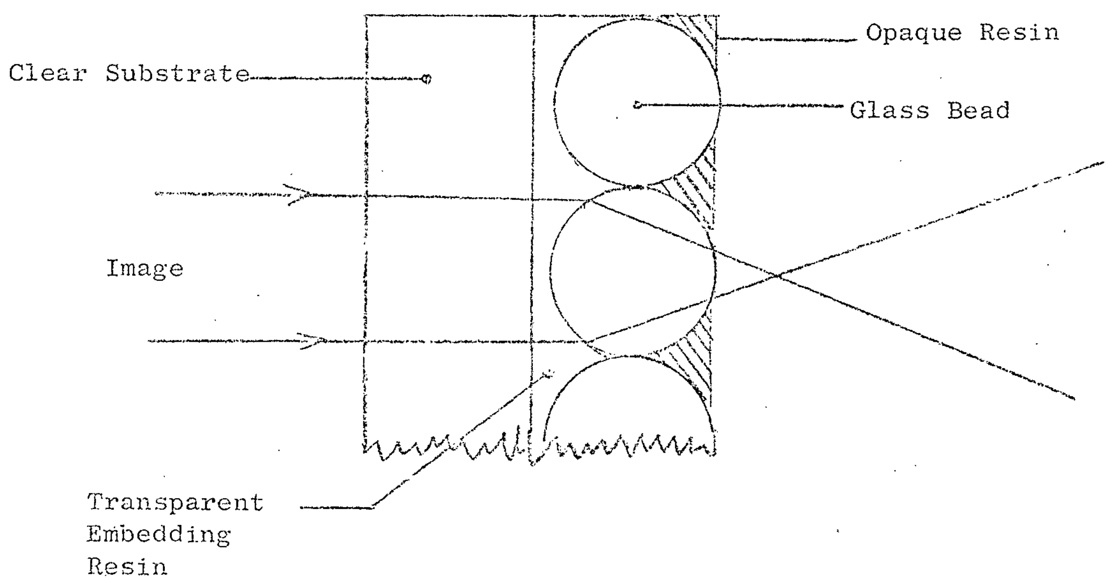
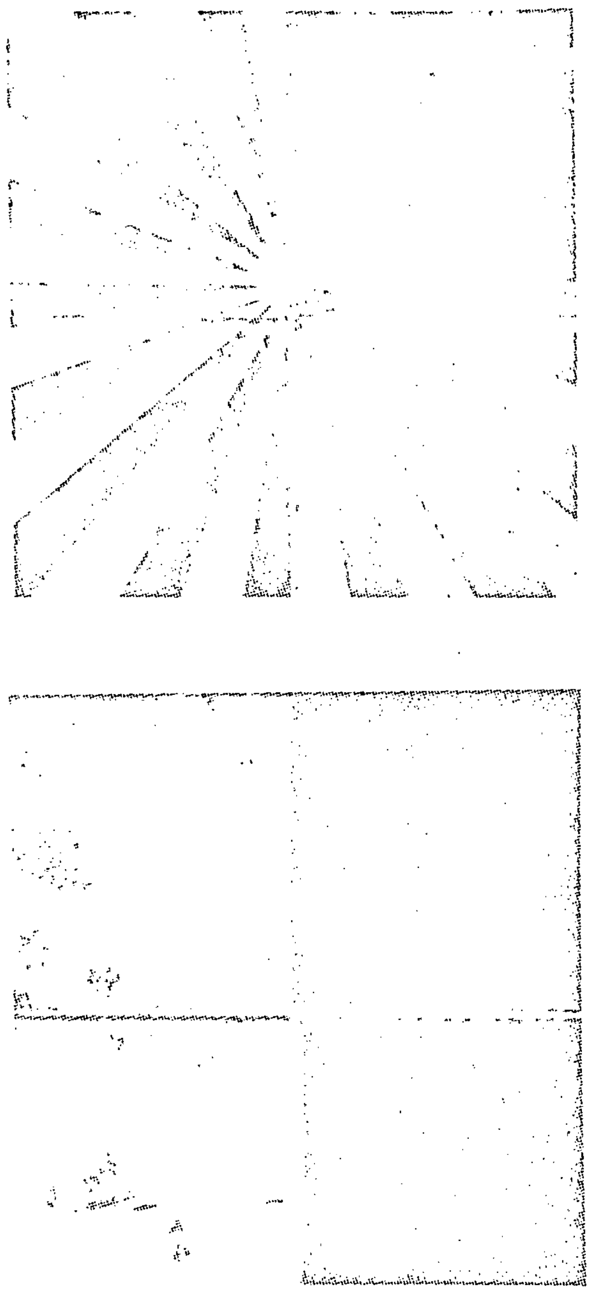


Figure 8. Regular and Masked Beaded Screens



A. With a Projected Image

B. Viewed in Reflected Light